

**"An optical multiplexer/demultiplexer"**

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The present invention relates to optical multiplexer/demultiplexer arrangements.

5       Such devices may find use i.a. in adding or dropping light signals at predetermined wavelengths to or from a wavelength division multiplex fiber optic transmission system.

10       For instance, in US-A-5 457 758 and US-A-5 459 801 an add-drop device for a wavelength division multiple fiber optic transmission system is disclosed along with a coupler adapted to be used to fabricate add-drop devices, dispersion compensators, amplifiers, oscillators, superluminescent devices, and  
15       communication systems. Essentially, the kind of device disclosed in those two documents includes an evanescent wave coupler having a coupling region formed from two single mode waveguides, the coupling region being formed so that there is substantially complete  
20       evanescent field coupling of light from one waveguide to the other in a predetermined wavelength band. The device has a Bragg grating disposed in the coupling region in each of the waveguides.

25       From WO-A-99/12296 a modular cascaded Mach-Zehnder DWDM component is disclosed adapted for use as a multiple channel fiber optic multiplexer, demultiplexer, multiplexer/demultiplexer and/or add-drop component. The device in question includes a plurality of Mach-Zehnder interferometer units, each  
30       unit including a pair of 50/50 fiber optic couplers connected by a pair of Bragg gratings and three functional ports including two multi-channel input/output ports as well as one single channel input/output port. The Bragg gratings are tuned to a  
35       wavelength of the single channel input/output port and

the input/output ports of adjacent interferometer units are connected to each other by fusion splices in a cascade configuration. The component includes a first common input/output connector on a first one of the cascaded interferometer units and a second common input/output connector on the last of the cascaded interferometer units, with the second common input/output connector arranged to permit the addition of add-on multi-channel components.

10 In US-A-5 657 406 a fiber optic wavelength multiplexer/de-multiplexer is disclosed including a plurality of 2X2 optical couplers each having a pair of matched gratings with respective bandpass wavelengths attached to two of the ports. An input signal enters a port and is split and reflected off the gratings and then recombined so as to provide all the input signal at an output port. Another input signal is incident on the grating which is passed by the grating and is coupled onto the output port with the first input signal. A similar arrangement exists for the other couplers connected in series each of which adds another input wavelength.

Also, from US-A-6 061 484 an add-drop multiplexer is known comprising passive optical components for wavelength division multiplexing. These add-drop multiplexers are adapted for use in branching units to allow signals passing along fibers of a main trunk between terminal stations to be dropped to and added from a spur station. The design of the add-drop multiplexer allows a reduced number of spur fibers to be used as signals are routed between trunk fibers at spur fibers according to carrier wavelength.

Essentially, all of the prior art solutions considered in the foregoing suffer from at least one of two basic disadvantages.

Firstly, they may tend to be fairly critical to realize (which is a typical drawback common to all arrangements generally referred to as Arrayed Waveguide Gratings or AWG).

5 Secondly, they tend to be inevitably difficult to compact in a small space if the number of tributary channels to be multiplexed/demultiplexed is high. This drawback is typical of directional couplers, which may also exhibit high insertion losses.

10 The main object of the present invention is thus providing a compact multiplexer/demultiplexer (MUX-DEMUX) for high numbers of optical channels adapted to be implemented as a compact integrated optics component, even in the presence of a high number of  
15 channels to be multiplexed/demultiplexed. The invention also aims at giving rise to arrangements which are not critical to be implemented from the technological viewpoint and, furthermore, are exempt from high insertion losses.

20 According to the present invention that object is achieved by means of an optical multiplexer/demultiplexer having the features specifically called for in the annexed claims.

In the presently preferred embodiment, the optical  
25 multiplexer/demultiplexer of the invention includes an integrated optics substrate such as a rectangular chip of silica on silicon or silica.

The substrate in question defines a main propagation path for the optical radiation arranged in  
30 a general zig-zag pattern with at least one cusp. Reflecting elements are arranged at the cusps of the zig-zag pattern to produce propagation of optical radiation along the main propagation path.

The main propagation path has an aggregate port adapted to act as an input/output port for an aggregate optical radiation including a plurality of wavelengths.

5 Distributed along the captioned main propagation path are a plurality of selective optical couplers preferably having associated therewith filter elements such as Bragg gratings adapted for adding to the aggregate optical radiation and/or removing from the aggregate optical radiation a respective tributary  
10 optical radiation centered around respective tributary wavelength.

The integrated optics substrate further defines a plurality of tributary propagation paths for optical radiation, each tributary propagation path extending  
15 between a respective optical coupler and a respective tributary port adapted to transmit (i.e. act as an input/output port for) a tributary optical radiation centered around a respective tributary wavelength.

Preferably, the integrated optics substrate is in  
20 the form of a strip (e.g. a rectangular chip) having opposed side surfaces, with the reflective elements including reflecting metallizations located at the opposed side surfaces of the strip. The reflecting metallizations are realised in the end surfaces of  
25 respective designed to obtain 50% energy coupling.

Still preferably, the lengths of the selective optical couplers are designed in order to obtain 100% energy transfer of the optical radiation propagated. The Bragg gratings are preferably provided in the  
30 centres of the respective couplers and exhibit a high degree of reflectivity (at least 35 dB). Preferably, the Bragg gratings are photoinduced in the integrated optic substrate.

According to the invention a high number of  
35 couplers with different gratings in order to

5 multiplex/demultiplex a correspondingly high number of optical wavelengths may be arranged in a small space. For instance a multiplexer/demultiplexer for use with 20-30 channels can be integrated in a small silicon or silica chip of a few square centimetres.

10 The invention will now be described, by way of example only, with reference to the annexed figure of drawing schematically showing the general layout of an integrated optics optical multiplexer/demultiplexer according to the invention.

In general terms, the device of the invention, indicated 1 overall, is intended to perform either of the following functions:

15 - demultiplexing an "aggregate" input optical radiation including a plurality of wavelengths  $\lambda_1$ ,  $\lambda_2$ , ...,  $\lambda_n$  to extract therefrom a corresponding plurality of tributary optical radiations each centered around a respective tributary wavelength (namely a first tributary wavelength  $\lambda_1$ , a second tributary wavelength  $\lambda_2$ , ... and an n-th tributary wavelength  $\lambda_n$ ), and

20 - multiplexing a plurality of tributary optical radiations at respective wavelengths (namely a first tributary radiation at wavelength  $\lambda_1$ , a second tributary radiation at wavelength  $\lambda_2$ , ... and an n-th tributary radiation at wavelength  $\lambda_n$ ) to give rise to an aggregate, wavelength division-multiplexed optical radiation including radiations at wavelengths  $\lambda_1$ ,  $\lambda_2$ , ...,  $\lambda_n$ .

25 The exemplary description of a preferred embodiment of the invention which follows will be primarily given with reference to operation as a demultiplexer. Those skilled in the art will however promptly appreciate that the arrangement and kind of operation described will immediately apply to the possible use of device 1 as a multiplexer.

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Also, it will be appreciated that the term "optical radiation" as used herein is in no way to radiation within the visible range of wavelengths, the term "optical" having to be understood as applying to  
5 all wavelengths (including infrared and ultraviolet radiation) generally considered in the field of the optical communications and processing of signals and in the area of integrated optics.

Device 1 is essentially comprises of an integrated  
10 optics substrate in the form of e.g. a rectangular chip 2 of silica on silicon or silica in which couplers, Bragg gratings and metallizations can be provided. This is done by resorting to known criteria and technology, thereby rendering any detailed description unnecessary  
15 herein.

The chip 2 comprising the integrated optics substrate is preferably in the form of a rectangular chip. This is shown in the drawing annexed as of indefinite length, such length being obviously dictated  
20 by the desired number of input/output ports to be included in the multiplexer/demultiplexer arrangement.

As shown herein, chip 2 has two opposed parallel side surfaces designated 3 and 4, respectively.

A main "aggregate" port 10 is provided at one of  
25 the captioned surfaces (surface 3, in the example shown herein) for transmitting an aggregate optical radiation including a plurality of wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_n$ .

"Transmitting" as used herein generally refers to the possible use of port 10 (and the other ports which  
30 will be referred to in the following) both for launching (i.e. inputting) and for withdrawing (i.e. outputting) optical radiation into and from substrate 2.

Starting from aggregate port 10 a main propagation  
35 path for optical radiation is provided in chip 2 (this

is done by resorting to current integrated optics optical waveguide technology) extending in a general zig-zag pattern.

Specifically, the captioned zig-zag pattern  
5 includes a plurality of cusps arranged in an alternate sequence at the opposite surfaces 3, 4 of chip 2.

Respective reflective elements, such as reflective metallizations M1, M2, M3, etc. are provided at the cusps of the captioned zig-zag pattern.

10 As a result of this, optical radiation injected into device 1 through aggregate port 10 will generally follow a propagation path leading from aggregate port 10 provided at side surface 3 of chip 2 towards a first metallization M1 provided at the opposite surface 4.  
15 Radiation impinging onto metallization M1 is then reflected back towards metallization M2 provided at the (opposite) side surface 3 and then on to metallization M3 provided again at surface 4 and so on.

In the exemplary embodiment shown herein five such  
20 metallization M1 to M5 are shown, but as many such metallizations may be provided as required depending on the number of tributary optical channels to be multiplexed/demultiplexed.

Couplers designated CR1, CR2, ..., CR5 are  
25 associated with metallizations M1, M2, ..., M5 respectively. The lengths of couplers CR1 to CR5 are computed to obtain 50% energy coupling and reflective metallizations M1 to M2 are realized in the end surfaces of these couplers.

30 References C1, C2, ..., C6 denote further selective couplers distributed along the main propagation path considered in the foregoing, coupler Cj being a generally located upstream of reflecting metallization Mj in the captioned propagation path starting from  
35 aggregate port 10: e.g. coupler C2 will be located

upstream of metallization M2 and downstream of metallization M1 in the direction of propagation of the aggregate optical radiation from input port 10.

5 Preferably, the lengths of couplers C1 to C6 are designed to obtain a 100% energy transfer for all the wavelengths at the input. At the centres of couplers C1 to C5 respective strong Bragg gratings R1 to R6 (having preferably a reflectivity value of at least 35 dB) are provided having respective Bragg wavelengths  $\lambda_1$ ,  $\lambda_2$ , ...,  $\lambda_6$ . Gratings R1, R2, etc. are preferably obtained by  
10 being photoinduced in chip 2.

Associated with each selective coupler C1 to C6 is a respective tributary propagation path for optical radiation.

15 Each such tributary propagation path extends between the respective coupler and a respective tributary port 11 to 16 adapted for transmitting a tributary optical radiation centered around a respective tributary wavelength  $\lambda_1$ ,  $\lambda_2$ , ...,  $\lambda_6$ .

20 For instance, a first tributary propagation path will extend between coupler C1 to port 11, while a second tributary propagation path will extend between coupler C2 and tributary port 12. A third tributary propagation path will extend between coupler C3 and  
25 tributary port 13, etc.

In use of the device 1 as a demultiplexer, an aggregate optical radiation including a plurality of wavelengths  $\lambda_1$ ,  $\lambda_2$ , ...,  $\lambda_n$  is injected into the device 1 at port 10.

30 As the aggregate optical radiation propagates along the zig-zag propagation pattern provided in substrate 2, the optical radiation at wavelength  $\lambda_1$  is reflected by grating R1 and caused to propagate towards port 11 from which it can be extracted.

5 All the other wavelengths in the aggregate radiation are transferred towards coupler CR1 that, in cooperation with metallization M1 acting as a reflective surface i.e. as a mirror, will send all the remaining radiation towards coupler C2. Coupler C2 and grating R2 will extract from the aggregate signal the component (channel) at wavelength  $\lambda_2$  which is sent towards port 12.

10 All the remaining signal components are sent towards coupler CR2 and reflecting metallization M2 to proceed towards coupler CR3 and grating R3, where the component at wavelength  $\lambda_3$  will be "stripped off" (i.e. extracted from) the aggregate radiation to be sent towards port 13.

15 The same mechanism described repaeats itself down to coupler C6 and Bragg grating R6 which will finally extract from the radiation path the component at wavelength  $\lambda_6$ , while any remaining wavelengths will be possibly propagated to a terminal port 17.

20 The underlying physical mechanism of reflection by a grating such as gratings R1 to R6 is well known in the art: see, for instance, F. Bakhti, P. Sansonetti, C. Sinet, L. Gasca, L. Martineau, S. Lacroix, X. Daxhelet, and F. Gonthier, "Optical add/drop multiplexer based on UV-written Bragg grating in a fused 100% coupler" - Electronics Letters 33, 803-804 (1997).

30 Operation of device 1 as a multiplexer is essentially identical to that described in the foregoing but for the fact that in multiplexer operation tributary optical radiations at wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_n$  are injected into device 1 at ports 11, 12, 13, ..., 1n to give rise to an aggregate multiplexed optical radiation leaving device 1 at port 10 acting as  
35 an output port.

For instance, when device 1 is used as a multiplexer, an optical signal at wavelength  $\lambda_2$  is injected through port 12 to be reflected by coupler C2 and Bragg grating R2 towards the coupler/mirror CR1/M1.

5 From there the signal in question is sent towards coupler C1 which transfers it towards aggregate port 10. In fact, such a signal at wavelength  $\lambda_2$  will not "see" grating R1 because the Bragg wavelength of this latter (i.e.  $\lambda_1$ ) is different.

10 As indicated, the arrangement of the invention enables a fairly high number of couplers with different gratings to be implemented to separate (demultiplex) or mix (multiplex) a corresponding number of different wavelengths in a relatively small space.

15 Couplers C1, C2, ... and CR1, CR2, ... as well as the other components of the device must of course be optimised.

Specifically, by resorting to known technologies, multiplexer/demultiplexer devices according to the  
20 invention can be implemented adapted for use with 20-30 channels on a silicon or silica chip having a surface of a few square centimetres.

Of course, the principle of the invention remaining the same, details and embodiments may be  
25 varied with respect to the exemplary embodiment disclosed herein without departing from the scope of the invention as defined in the annexed claims.